Future opportunities from MTG and Post-EPS

Johannes Schmetz

With thanks to Rolf Stuhlman, Peter Schlüssel and many colleagues

EUMETSAT
Darmstadt, Germany

Content:

- EUMETSAT programmes: current and future
- Current utilisation => best first guess for future
- Meteosat Second Generation
- Evolution to MTG
- EUMETSAT Polar Programme/Metop
- Evolution to Post-EPS
- A look at (or gleaning from) our partner NOAA/NESDIS
- Examples for future opportunities
- Importance of calibration

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FROM THE EUMETSAT CONVENTION

- **“ The primary objective ... is to establish, maintain and exploit European systems of operational meteorological satellites..... “**
- **“ A further objective ... is to contribute to the operational monitoring of the climate and the detection of global climatic changes.“**

EUMETSAT's mission is:

- **To deliver cost efficient operational satellite data and products …. satisfy …. requirements of its Member States,**
- **taking into account the recommendations of the World Meteorological Organization.**

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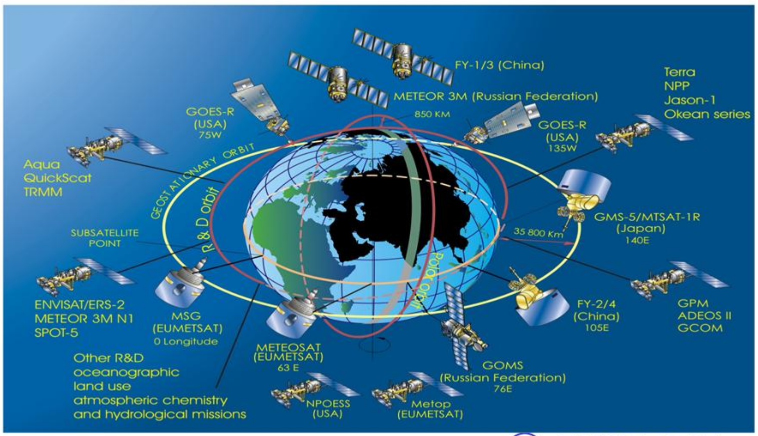
Current Space Based Components of the Global Observing System



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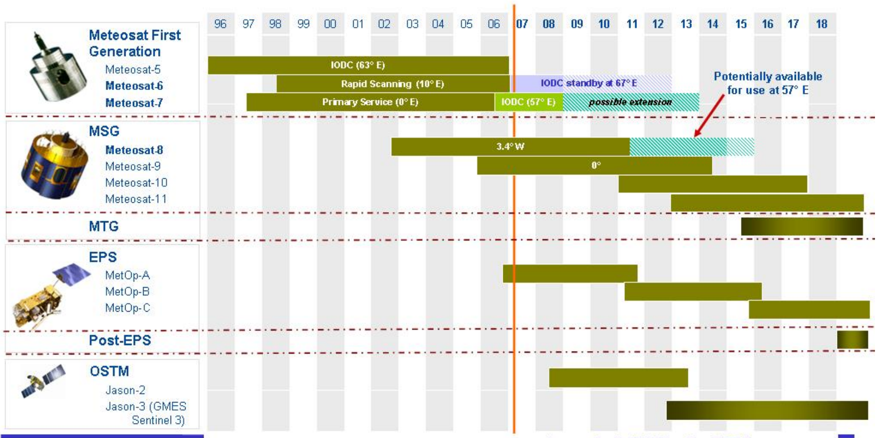
EUMETSAT Programme Planning



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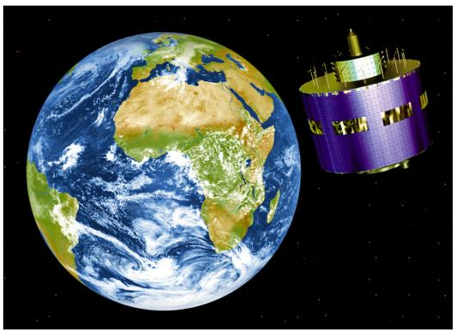
Meteosat Second Generation:

A breakthrough for meteorology



- Imager with 12 spectral channels
- Full-disk repeat cycle of 15 minutes
- Spatial sampling 3 km (1km for high resolution visible channel)
- On-board calibration for infrared channels
- GERB instrument => radiation budget
- Meteosat-8 (2002)
- Meteosat-9 (2005)
- Two more to follow

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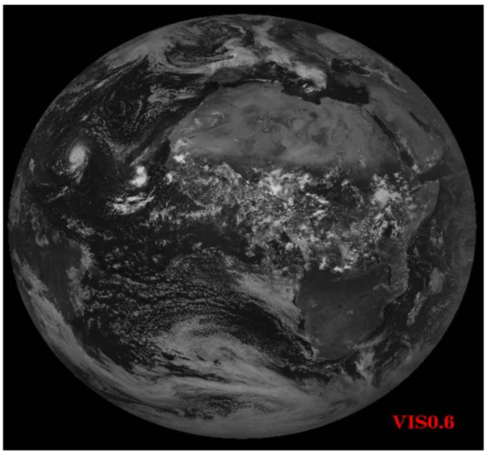
Twelve spectral channels of Meteosat Second Generation



• so far in space Meteosat-8 and -9

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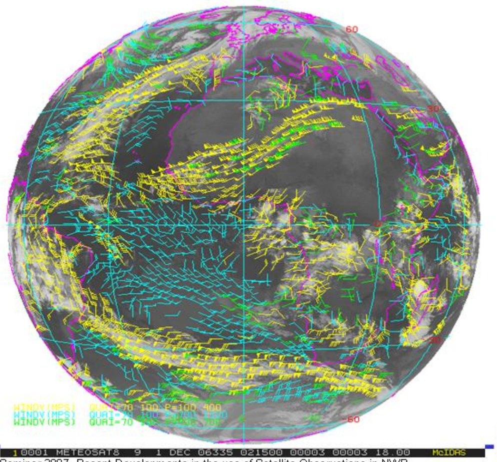
Winds for Numerical Weather Predictions
(see also presentation by M. Forsythe on 3 September)



Winds from tracking atmospheric motions

here:
10.8 µm channel

R. Borde, 2006

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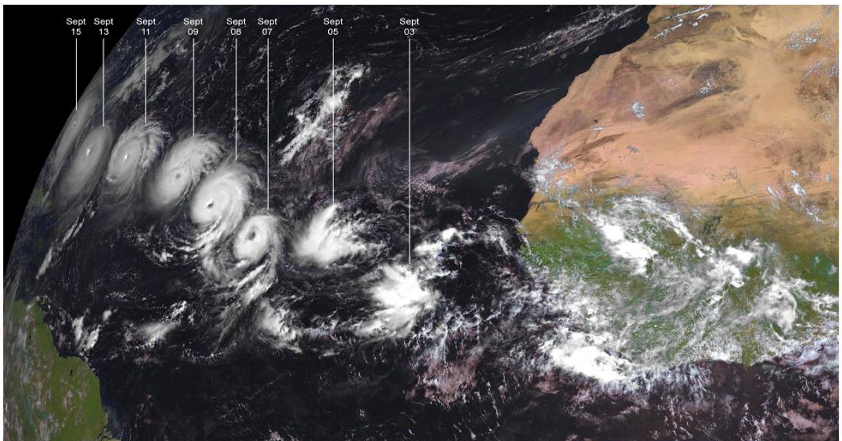
Observing the cradle of hurricanes: Combination of VIS images from Meteosat- 8 tracks Hurricane Isabel (September 2003)



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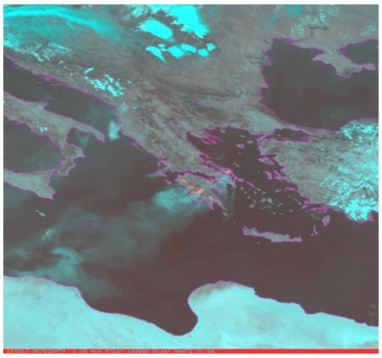
Fire detection from MSG (=> perspective with MTG)

Forest fires in Greece

Meteosat-9, 25 August 2007, 1200 UTC



Modis on Aura

H.J. Lutz, 2007

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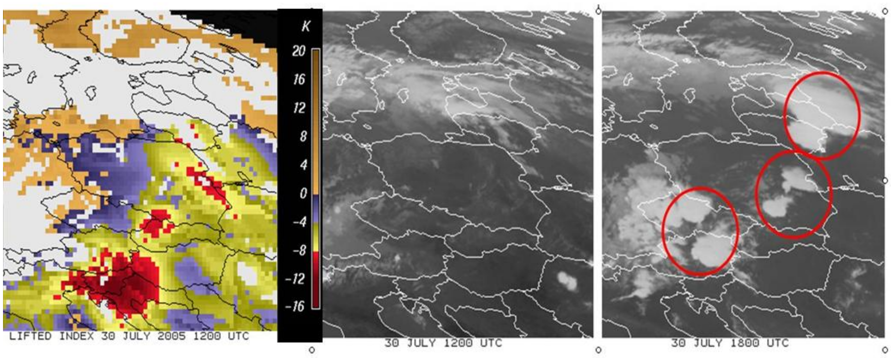
Meteosat monitors onset of convection

M. König, 2006

Lifted index at 1200 UTC — **10.8µm image at 1200 UTC** — **10.8µm image at 1800 UTC**



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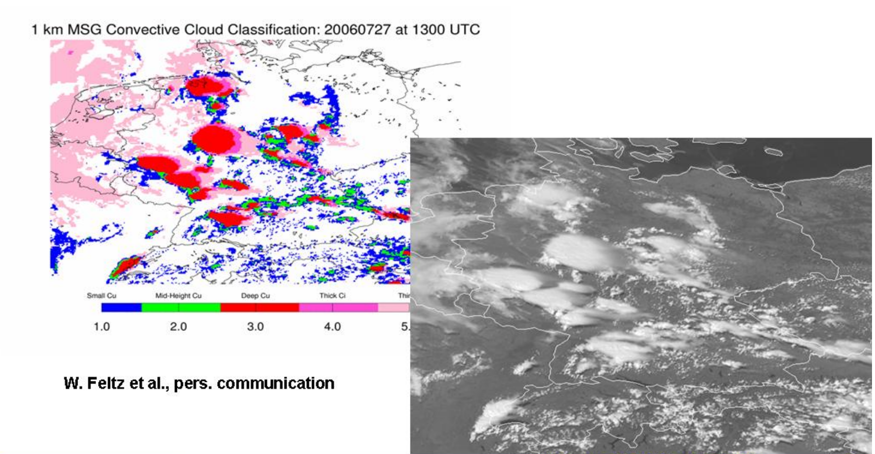
Example of Convective Cloud Mask Product from MSG



W. Feltz et al., pers. communication

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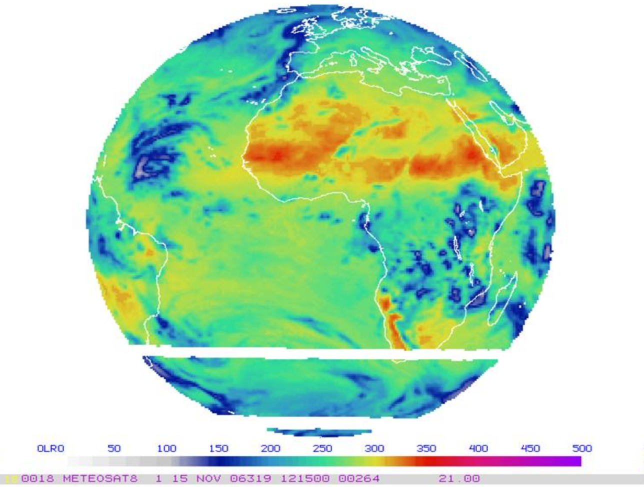
Example of a climate product: Outgoing Longwave Radiation (OLR) *(courtesy M. König)*



Bias

GERB – SEVIRI:

-1.3 to -1.9 Wm^{-2}

Future geostationary programme

Meteosat Third Generation (MTG)

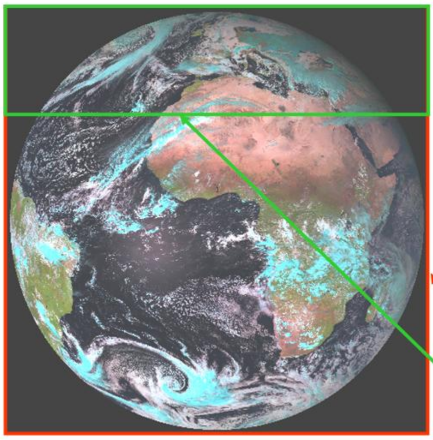
Focus is on Numerical Weather Prediction and Nowcasting.

Candidate missions:

- High Resolution Fast Imagery (HRFI) mission.
- Full Disk High Spectral Imagery (FDHSI) mission.
- Infrared Sounding (IRS) mission.
- Lightning Imagery (LI) mission.
- UV-VIS Sounding (UVS) mission.

The need date is 2015.
Technical analysis with ESA.

MTG Imagery Missions



- **MTG imagery missions served by a Flexible Combined (FC) imager**
- **Use of in-orbit spare satellite for rapid scan**

FDHSI mission (continuation of MSG-SEVIRI):
FC imager on the operational satellite in Full Disk mode with 10 min repeat cycle

HRFI mission (continuation of Rapid Scan):
FC imager on fully commissioned in-orbit hot stand-by in Rapid Scan mode over ¼ of Full Disk with 2.5 min repeat cycle

	Coverage	Repeat cycle
FDHSI mission	Full Disk	10 min
HRFI mission	1/4 FD	2.5 min

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MTG Imager Requirements

'Core' channels	Meteosat 1st Generation Central wavelength (μm)	Meteosat 1st Generation Width (FWHM) (μm)	Meteosat 1st Generation Spatial Sampling (km)	Meteosat 2nd Generartion Central wavelength (μm)	Meteosat 2nd Generartion Width (FWHM) (μm)	Meteosat 2nd Generartion Spatial Sampling (km)	Meteosat 3rd Generation Central wavelength (μm)	Meteosat 3rd Generation Width (FWHM) (μm)	Meteosat 3rd Generation Spatial Sampling* (km)
FC -VIS 0.4							0.444	0.06	1.0
FC -VIS 0.5							0.510	0.05	1.0
FC -VIS 0.6	0.7	0.35	2.5	0.635	0.08	3.0	0.645	0.08	0.5
FC -VIS 0.8				0.81	0.07	3.0	0.86	0.07	1.0
FC -NIR 0.9							0.96	0.06	1.0
FC -NIR 1.3							1.375	0.03	1.0
FC -NIR 1.6				1.64	0.14	3.0	1.61	0.06	1.0
FC -NIR 2.1							2.26	0.05	0.5
FC -IR 3.8 *				3.9	0.44	3.0	3.8	0.40	1.0
FC -IR 6.7	6.1	1.3	5.0	6.3	1.0	3.0	6.3	1.00	2.0
FC -IR 7.3				7.35	0.5	3.0	7.35	0.50	2.0
FC -IR 8.5 *				8.7	0.4	3.0	8.7	0.40	2.0
FC -IR 9.7				9.66	0.3	3.0	9.66	0.30	2.0
FC -IR 10.8	11.5	1.9	5.0	10.8	1.0	3.0	10.5	0.7	1.0
FC -IR 12.0				12.0	1.0	3.0	12.3	0.5	2.0
FC -IR 13.3				13.4	1.0	3.0	13.3	0.60	2.0
Repeat Cycle :	30 min			15 min			10 min		

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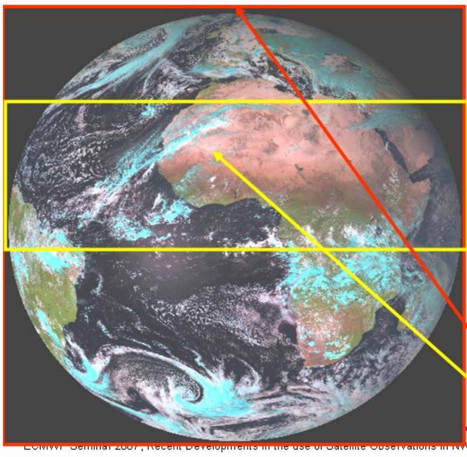
MTG Infrared Sounder (IRS)



Mission Band	Frequency range cm^{-1}		Main Contribution
IRS-1	700	770	CO_2
IRS-2	770	980	Surface, Clouds
IRS-3	980	1070	O_3
IRS-4	1070	1210	Surface, Clouds
IRS-6	1600	2000	H_2O,
IRS-7	2000	2175	CO,

1800 channels
Spec.res. 0,62 1/cm

	Coverage	Repeat cycle
Full Disk Coverage	18°x18°	30 min
Local Area Cov.	18°x6°	10 min

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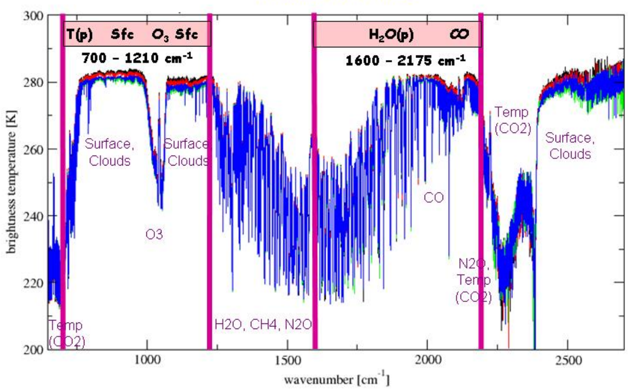
MTG InfraRed Sounder (IRS)

First IASI Level 1C Spectra

29/11/2006, 13:42:11 UTC



MTG spectral coverage

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IASI

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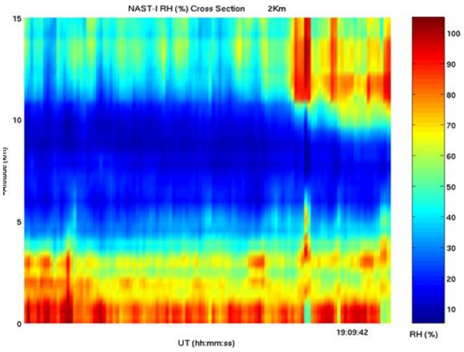
MTG Infrared Sounder (IRS)

Hyperspectral IR sounding with focus on time evolution of vertically resolved water vapour structures

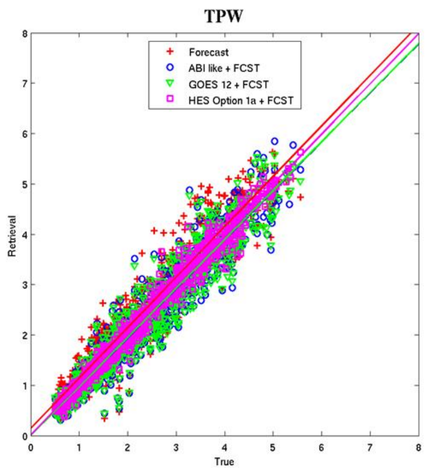


Priorities IRS Mission

- Atmospheric dynamic variables with high vertical resolution (e.g. water vapour flux, wind profile, transport of pollutant gases)
- More frequent information on Temperature and Humidity profiles for NWP (regional and global)
- Monitoring of instability / early warning of convective intensity
- Cloud microphysical structure
- support chemical weather and air quality applications

	Coverage	Repeat cycle
Full Disk Coverage	18°x18°	30 min
Local Area Cov.	18°x6°	10 min

Benefits of high-spectral over broad-band measurements!



Total Precipitable Water (TPW) from high-spectral (HES) data much improved over current broadband (GOES-12 + forecast).

Menzel et al. (2007)

Root Mean Square Error	
Forecast:	0.40
ABI like + fcst:	0.35
GOES 12 + fcst:	0.34
HES + fcst:	0.16

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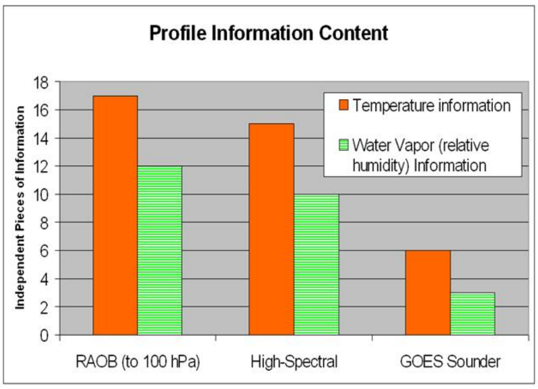
Information content



The relative vertical information is shown for radiosondes, a high-spectral infrared sounder and the current broad-band GOES Sounder. The high-spectral sounder is much improved over the current sounder.

Figure courtesy of A. Huang

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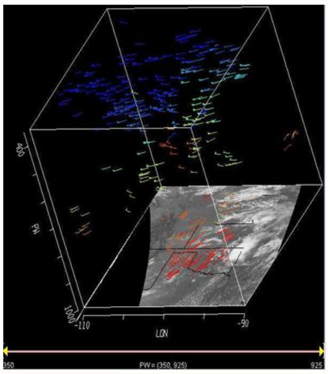
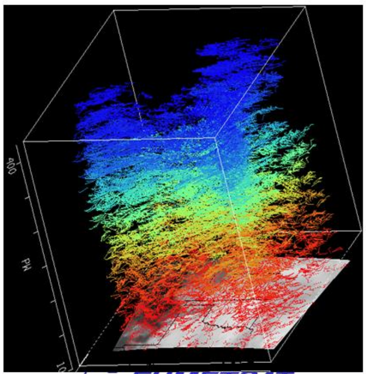
Greatly Improved Atmospheric Motion Vectors with hyperspectral sounder

(Figure courtesy of C. Velden)

Current GOES



High-spectral



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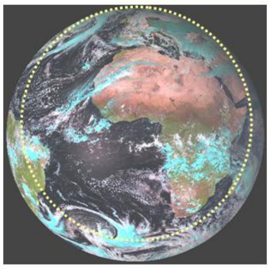
MTG Lightning Imaging Mission

User Request: detect 90% of lightest events
In Cloud (IC), Cloud to Cloud (CC), and Cloud to Ground (CG)



FOV	16° Earth Disk ~ 80% of the Full Disk
IFOV – Spatial Resolution	10 km (45 degree North)
Wavelength	Neutral oxygen line OI(1) at 777.4 nm
Integration time	2ms - 1ms optimised to meet DE and FAR
Discharge optical pulse	0.5ms
Energy range	4 - 400 $\mu J m^{-2} sr^{-1}$
Detection Efficiency (DE)	> 90% - 40% for any individual event
False Alarm Rate (FAR)	< 1 flash/sec *(averaged over the full Earth, assuming 50% cloud cover)*
Repeat cycle	continuous (as integration time)
Accuracy	intensity better 50% (20% goal)

Co-registration HRFI/FDHSI: better than 1 IFOV

event: single CCD-pixel above energy threshold integrated over time (1 – 2 ms)
group: optical pulse associated with a single discharge of a CG return stroke or a recoil streamer of IC/CC
flash : lightning flash, consisting of several discharges – strokes/recoil streamer - separated by 50-300 ms close in space
(65 % of all flashes consists of more than 5 groups)
(90% of all flashes have a discharge event with radiances above 10 $\mu J m^{-2} sr^{-1}$)

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Continuation and enhancement of Geostationary Services

- Absorbed Shortwave Radiation
- Active Fire Detection / Monitoring
- Aerosol/Dust Detection
- Aerosol Optical Thickness
- Aerosol Particle Size
- All Sky Radiances
- Aircraft Icing Threat
- Air Mass Analysis
- Atmospheric Moisture Profile
- Atmospheric Temperature Profile
- Capping Inversion Information
- Clear Sky Masks
- Clear Sky Radiances
- Clear Sky Reflectance Map
- Climate Data Set
- Cloud Coverage
- Cloud Ice Water Path
- Cloud Imagery
- Cloud Layers / Heights and Thickness
- Cloud Liquid Water
- Cloud Mask
- Cloud Optical Depth
- Cloud Particle Size Distribution
- Cloud Top Height

- Cloud Top Phase
- Cloud Top Pressure
- Cloud Top Temperature
- Cloud Type
- CO Concentration
- Convection Initiation
- Atmospheric Motion Vectors
- Downward Longwave Irradiance
- Downward Shortwave Irradiance
- Emitted Longwave Radiative Flux TOA
- Enhanced Overshooting Top Detection
- Fire Radiative Power
- Fire Radiative Energy
- Flood/Standing Water
- Global Instability Indices
- High Resolution Precipitation Index
- Humidity Products (upper/midlevel rel. Hu)
- Ice Covered Land
- Land Surface (Skin) Temperature
- Lightning Detection
- Low Cloud and Fog
- Moisture Flux
- Ozone Layers
- Ozone Total

- All Sky Radiances
- Rainfall Potential and Probability
- Rainfall Rate/ Multisensor QPE
- Reflected Solar Radiative Flux TOA
- Scene Analysis
- Sea & Lake Ice/Age
- Sea & Lake Ice/Concentration
- Sea & Lake Ice/ Displacement and Direction
- Sea & Lake Ice/Extent and Characterization
- Sea Surface Temperature
- Snow Cover
- SO_2 Concentration
- Surface Albedo
- Surface Emissivity
- Total Precipitable Water
- Total Water Content
- Turbulence
- Upward Longwave Radiation at Surface
- Vegetation Fraction LAI
- Vegetation Index
- Visibility
- Volcanic Ash
- Wind Divergence

Service supported by:

MTG Flexible Combined Imager	MTG Infrared Sounder	MTG Lightning Imager

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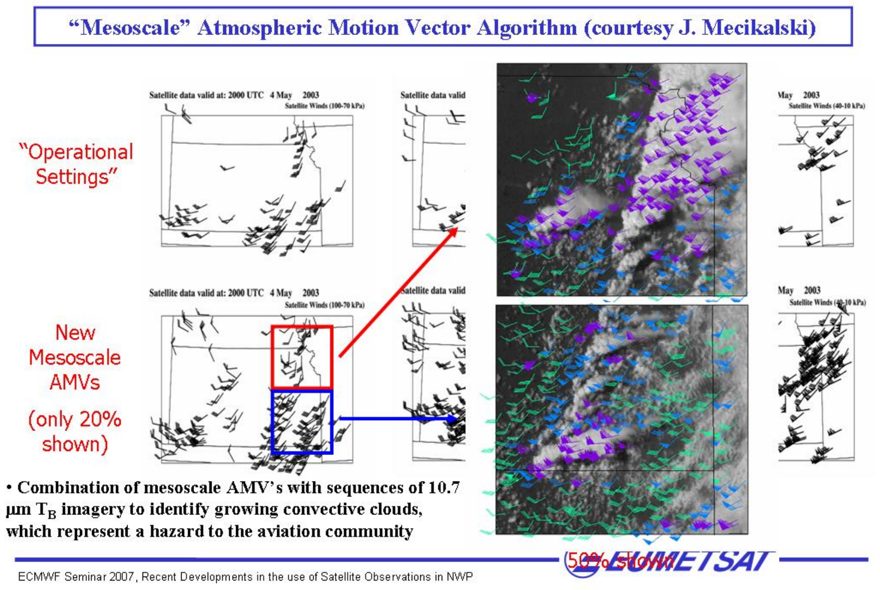
"Mesoscale" Atmospheric Motion Vector Algorithm (courtesy J. Mecikalski)
"Operational Settings"
New Mesoscale AMVs
(only 20% shown)
Satellite data valid at: 2000 UTC 4 May 2003
• Combination of mesoscale AMV's with sequences of 10.7 μm T_B imagery to identify growing convective clouds, which represent a hazard to the aviation community
(50% shown)
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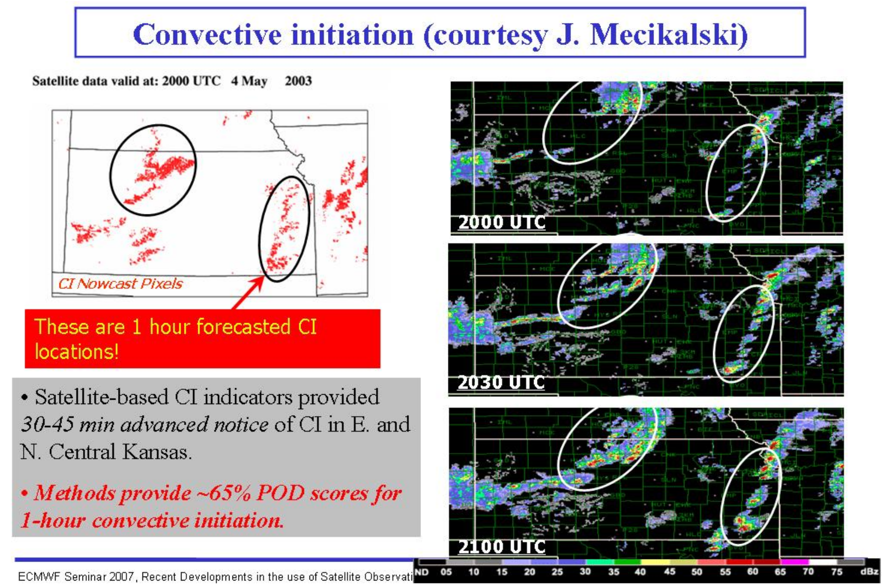
Convective initiation (courtesy J. Mecikalski)
Satellite data valid at: 2000 UTC 4 May 2003
CI Nowcast Pixels
These are 1 hour forecasted CI locations!
• Satellite-based CI indicators provided 30-45 min advanced notice of CI in E. and N. Central Kansas.
• Methods provide ~65% POD scores for 1-hour convective initiation.
2000 UTC
2030 UTC
2100 UTC
ND 05 10 15 20 25 30 35 40 45 50 55 60 65 70 75 dBz
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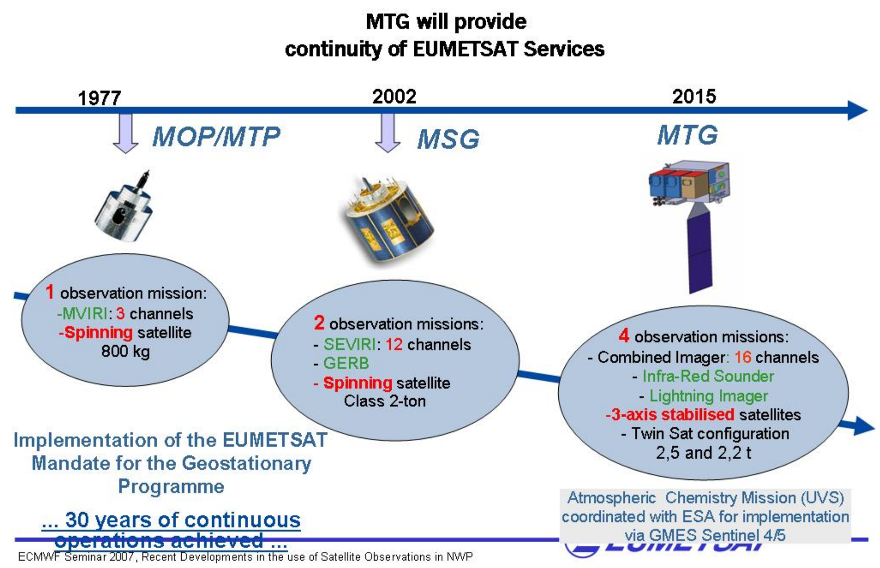
MTG will provide
continuity of EUMETSAT Services
1977
2002
2015
MOP/MTP
MSG
MTG
1 observation mission:
-MVIRI: 3 channels
-Spinning satellite
800 kg
2 observation missions:
- SEVIRI: 12 channels
- GERB
- Spinning satellite
Class 2-ton
4 observation missions:
- Combined Imager: 16 channels
- Infra-Red Sounder
- Lightning Imager
-3-axis stabilised satellites
- Twin Sat configuration
2,5 and 2,2 t
Implementation of the EUMETSAT Mandate for the Geostationary Programme
... 30 years of continuous operations achieved ...
Atmospheric Chemistry Mission (UVS) coordinated with ESA for implementation via GMES Sentinel 4/5
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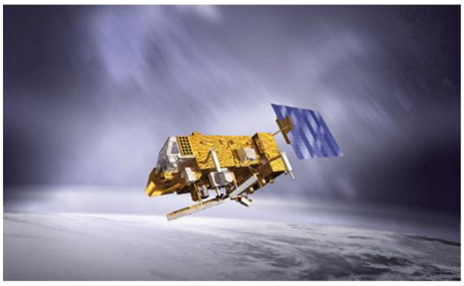
Polar-orbiting Satellites (Metop)

EUMETSAT Polar System (EPS)



EUMETSAT Polar System (EPS):

- a series of three Metop satellites
- operate over at least 14 years.

- Metop A launched in October 2006

- Metop also contributes to oceanography, environmental observations and fosters research

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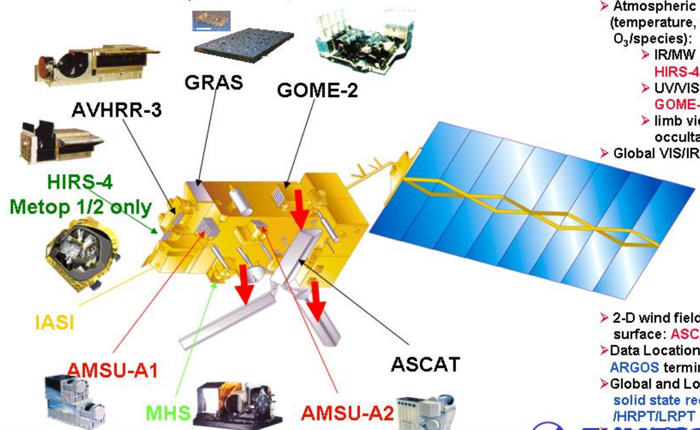
EUMETSAT Polar System: Space Segment
Metop Satellite, Instruments and Missions



- Atmospheric Sounding (temperature, moisture, O_3/species):
  - IR/MW imaging sounders: HIRS-4/IASI, AMSU-A/MHS
  - UV/VIS imaging sounder : GOME-2
  - limb viewing radio-occultation sounder: GRAS
- Global VIS/IR Imagery: AVHRR/3

- 2-D wind field at the ocean surface: ASCAT
- Data Location and Collection: ARGOS terminal
- Global and Local Data Access: solid state recorder /HRPT/LRPT
- Search & Rescue Terminal

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Metop instruments: Continuity + heritage + novel technology

- Continuity:
- - Imaging => AVHRR (NOAA)
- - Sounding => HIRS (NOAA), MHS, AMSU-A (NOAA)
-
- Science heritage:
- - GOME-2 => ozone, aerosol, trace gases (ESA)
- - ASCAT => ocean surface winds (ESA)

- Novel:
- Hyperspectral sounding => IASI (CNES)
- Radio-occultation => GRAS

- => Initial Joint Polar System with NOAA

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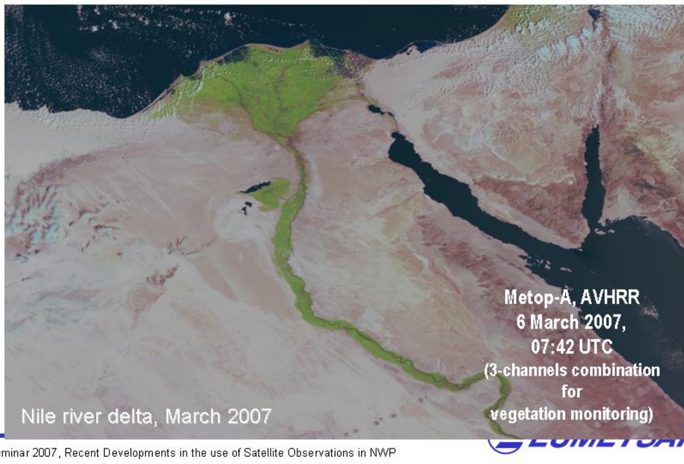
Global imaging



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IASI

- Covered by dedicated talk by P. Schlüssel

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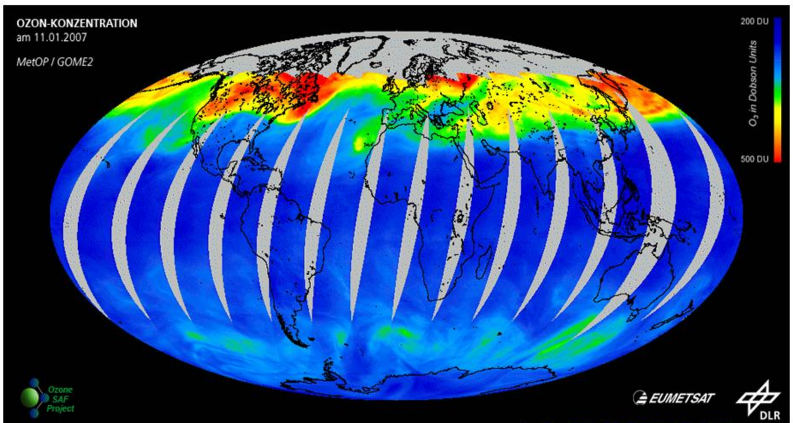
GOME-2 Ozone measurements

Provided courtesy of DLR (O3MSAF) http://wdc.dlr.de/sensors/gome2/index.html



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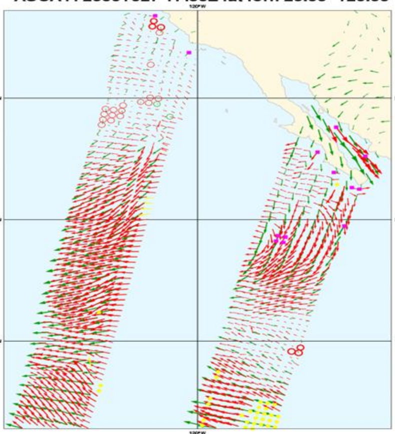
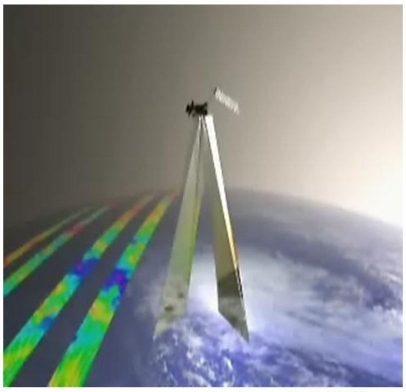
Winds from ASCAT compared with ECMWF

ASCAT: 20061027 17:30Z lat lon: 20.00 -120.00





Courtesy, ESA, 2006

Level-2 processing at OSI-SAF, KNMI

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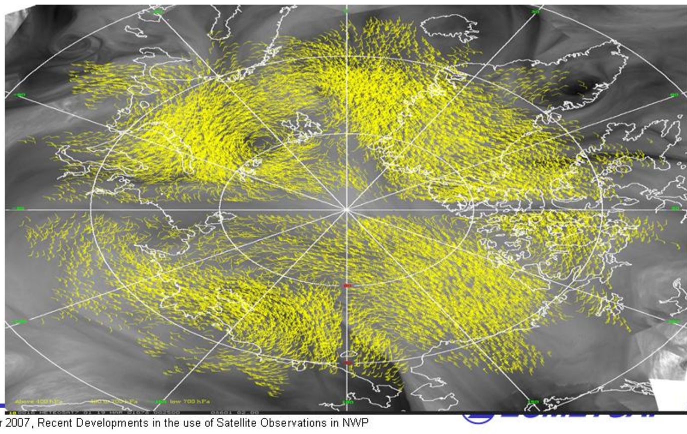
Winds over polar regions (composite from MODIS), Key et al. 2003

⇒Large positive impact on forecasts

⇒

need to derive winds from AVHRR



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EUMETSAT Strategic Guidelines for Post-EPS

EUMETSAT will remain committed, as a minimum and top priority, to the mid - morning sounding mission

There is a joint commitment between EUM Member States and NOAA for a future Polar System (JPS)

Possible EUMETSAT contribution to a JPS fully open:

- instruments across the various orbits;
- satellites on different orbits; etc.

EUMETSAT will keep responsibility for at least one end-to-end system

Need date for the core mission with instruments for Atmospheric Temperature and Humidity Sounding 2018 (1st piority) , followed by the remaining missions in 2020

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Future polar programme
Post-EPS

For Post - EPS the user needs in the following areas are considered as result of User Consultation through Expert Groups:

Atmospheric Chemistry;
Atmospheric Sounding and Wind Profiling;
Climate Monitoring;
Cloud, Precipitation and Large Scale Land Surface Imaging;
Ocean Surface Topography and Imaging;
Nowcasting and NWP.

The need date is 2019 and the mission will be balanced with GMES and GEO needs.
Joint technical analysis with ESA.

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Post-EPS Candidate Missions

Name	Rank
High-Resolution Infrared Sounding (IRS)	3
Microwave Sounding (MWS)	3
Scatterometry (SCA)	3
VIS/IR Imaging (VII)	3
Microwave Imaging (MWI) - Precipitation	2
Microwave Imaging (MWI) - Ocean and Land	2
Radio Occultation Sounding (RO)	2
Nadir viewing UV/VIS/NIR - SWIR Sounding (UVNS)	1
Doppler Wind Lidar (DWL)	1
Multi-viewing, Multi-channel, Multi-polarisation Imaging (3MI)	1
Dual View Radiometry (DVR)	1
Radar Altimetry (ALT)	1

Note: Rank value 3: highest priority

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'Near' simultaneous observations from space for operational Earth observation – Example: The A-Train (courtesy NASA)

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Thought on a deployment secenario: 'Near' simultaneous observations from polar orbit for operational Earth observation:

- **4-D Var assimilation makes need for distribution of observations over time less critical**
- **For process studies and research near simultaneous observations are essential => this will advance understand and utilisation of data**

➢ **Trains of satellites might be an option for operational observations … serves operational (NWP) requirements and fosters research/utilisation**

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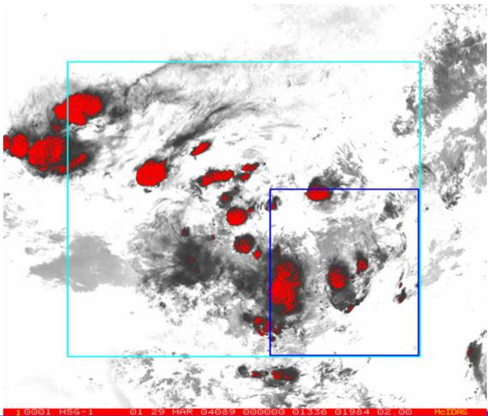
Meteosat-8 monitors deep convective clouds



Red pixels:
T6.2 > T10.8

How can this be explained?

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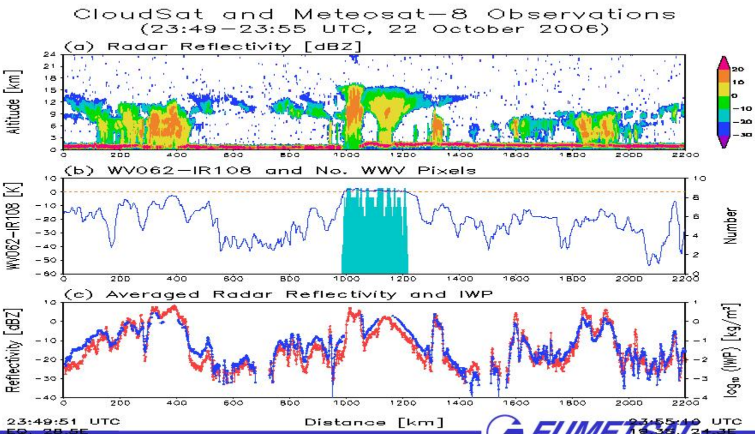
Cloudsat explains physics in areas with T6.2 > T10.8
(from Cloudsat website and adapted by Chung et al., 2007)



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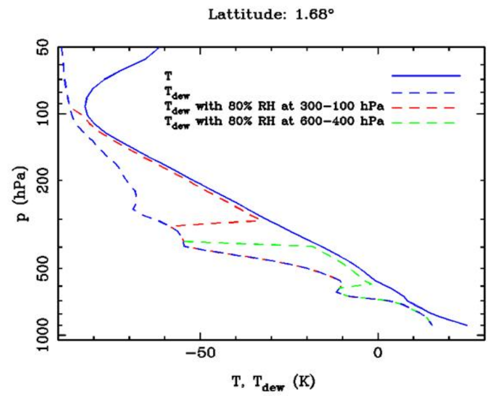
Input data for IASI simulated spectra for a tropical atmosphere



IASI simulation by X. Calbet, personal ommunication

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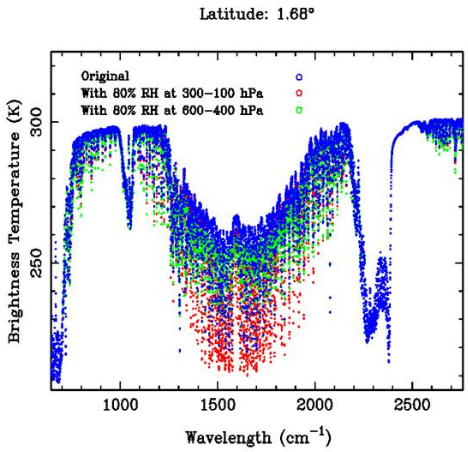
IASI simulated spectra for a tropical atmosphere



A hyperspectral sounder in a geostationary orbit could vertically slice and track the moisture outflow in tropical convective regions

⇒ an important process in the global water cycle
⇒ e.g. moistening of the UTLS

IASI simulation by X. Calbet, personal communication

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Reasons behind improvements in NWP due to satellite data

(from Uccellini, 2007)

- Improvement due to a balance among
  - Observations
  - Data Assimilation & Model technology
  - Computing resources
- Estimated 30 - 40% of improvement from observations (principally global LEO satellite data) and 60 - 70% from data assimilation and modeling techniques and computing resources

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Need to foster utilisation and continuous development has been recognised:
=> De-centralised applications ground segment:
Satellite Application Facilities (SAF)

- Support to Nowcasting and Very Short Range Forecasting
- Ocean and Sea Ice
- Climate Monitoring
- Numerical Weather Prediction
- Land Surface Analysis
- Ozone & Atmospheric Chemistry Monitoring
- GRAS Meteorology
- Support to Operational Hydrology and Water Management

=> BENEFITS:

- Makes use of European expertise,
- Fosters cooperation and utilisation,
- Maximises return on investment

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The importance of good satellite calibration
=> GSICS (Global Space-based Inter-Calibration System)

- To improve the use of space-based global observations for weather, climate and environmental applications through operational inter-calibration of satellite sensors.
- Improve global satellite data sets by ensuring observations are well calibrated through operational analysis of instrument performance, satellite intercalibration, and validation over reference sites
- Provide ability to re-calibrate archived satellite data with consensus GSICS approach, leading to stable fundamental climate data records (FCDR)
- Ensure pre-launch testing is traceable to SI standards
- => Under WMO Space Programme
  - GSICS Implementation Plan and Program formally endorsed
  - at CGMS 34 (11/06)

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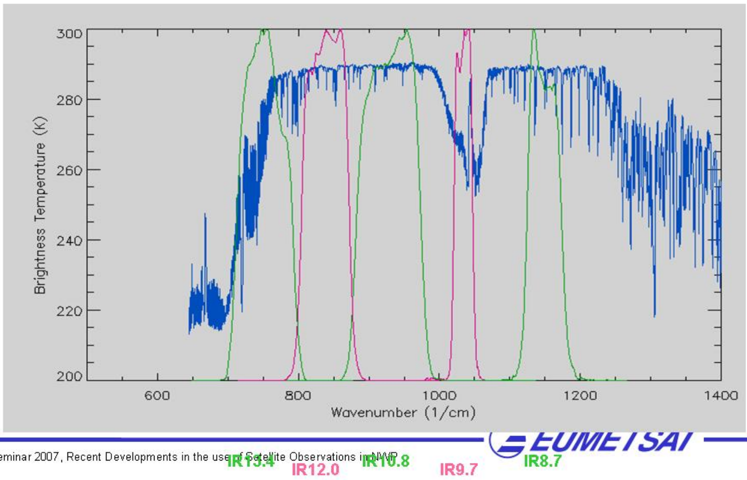
GSICS: Intercalibrating MSG with IASI



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IASI – like instruments will be excellent reference for calibration => climate monitoring

Channel	ΔT IASI – Meteosat-8*	ΔT IASI – Meteosat-9 *
IR3.9	-0.17	-0.20
WV6.2	-0.24	-0.40
WV7.3	-0.51	-0.14
IR8.7	0.15	0.15
IR9.7	0.17	0.20
IR10.8	0.16	0.07
IR12.0	0.19	0.08
IR13.4	0.44	1.7

*Uncertainty 0.1 – 0.2 K

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Conclusion (1)

- Operational satellites do provide important contribution to meteorological services
- Need for continuous development of utilisation techniques (e.g. algorithms, timeliness, interpretation, …)
- Future satellite missions hold promise for improved weather forecasting, better climate monitoring and better understanding of physical processes
- Realisation of future satellite systems is result of competing and complementary interests from: i) Existing operational requirements, ii) Science and anticipated future applications, iii) Technical constraints (feasibility), iv) Political considerations and v) Affordability

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Conclusions (2)

- EUMETSAT satellite systems (Meteosat and Metop) are key elements of the operational space-based observing system
- Continuity and serving the evolving needs of our Member States has highest priority
- EUMETSAT's International partnership (e.g. the Joint Polar System with NOAA) ensures a European contribution to a Global Earth Observation System of Systems (GEOSS) that are mutually consistent and also cost-effective
- EUMETSAT mandate evolves, therefore a further priority is to develop new activities in operational oceanography and atmosphere monitoring jointly with partners (ESA, NOAA, ….)
- More information (including SAF links): www.eumetsat.int

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